NERVE ENDINGS IN HUMAN TEETH

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THE controversy over the termination of sensory nerves in teeth has been concerned mainly with two opposed theories: (i) that the fine nerve fibres enter the dentinal tubes and terminate near the enamel, (ii) that the nerves end in association with the odontoblasts.

The supporters of the former view are especially impressed with the extreme sensitiveness of exposed dentine to stimuli such as slight touch or contact with certain non-volatile chemical substances, i.e. stimuli which cannot owe their effects to mechanical pressure on the underlying pulp or to sudden application of cold to it.

A histological basis for the theory was forthcoming in the work of Boll (1868), who believed he could demonstrate in material prepared with chromic acid a system of nerve fibres entering the dentinal tubes. In the light of present knowledge Boll's method must be regarded as inadequate. Römer (1899) and more recently Dependorf (1913) and Fritsch (1914) have also described an innervation of dentine. The extreme view is expressed in the work of Morgenstern (1896) who believed he could detect in Golgi preparations a dense meshwork of nerve fibres traversing the dentine in all directions, and with nerve cells lodged in the dentinal tubes. The most elaborate recent work in which similar conclusions have been reached is that of the late J. H. Mummery (1919). By a special gold method he found it possible to demonstrate fine fibres entering the dentinal tubules from the pulp, and accompanying the dentinal fibres (Tomes' fibres) throughout the dentine. He believed he could show the origin of these fine fibres from nerve cells lying just below the odontoblast layer; and that the coarse medullated nerves from the pulp, approaching the odontoblast layer, broke up into a brushwork of fibrils which formed synapses with these nerve cells.

In a recent re-examination of this work Stewart (1927) finds that Mummery's fibres do not disappear if the inferior dental nerve be cut and allowed to degenerate. Of course if they are the axons of peripheral nerve cells, located as Mummery thought in the pulp, degeneration should not occur. Stewart, however, fails to find any connection between these fibres and supposed nerve cells in the pulp; and it would certainly seem that, if the axons stained in such large numbers, their cell bodies, were they present, would not remain entirely uncoloured. He concludes that unless nerve fibres have reached the teeth via the inferior dental artery, Mummery's fibres cannot be nerves.

The belief that the pulp nerves end in the odontoblast layer originated with Retzius (1892, 1893, 1894) by the use of Golgi preparations of teeth from young fishes, amphibians and reptiles, as well as from a young mouse. Huber (1898) confirmed Retzius' conclusions in methylene blue preparations of rabbit teeth. Retzius and Huber both thought that the nerves ended free among the odontoblasts. Hopewell-Smith (1918), who devoted much time to the matter, concluded that the nerves "terminate in a basket-work of varicose fibres embracing and often closely attached to the cell walls of the individual odontoblasts."

If the nerves end only in association with the odontoblasts, then it is to these cells that the sensitiveness of dentine must be ascribed. The apparent sensitiveness of the enamel may find an explanation in the recent work of Loher (1929) and Allen (1930) who have been able to trace the dentinal processes beyond the limits of the dentine into the enamel. The mesenchymal rather than epiblastic origin of the odontoblasts has been urged as an objection to their serving as pain receptors. But there is no *a priori* reason why sense cells should be exclusively epiblastic; they are predominantly so because it is this layer that is most likely to come in contact with the outer world.

MATERIAL AND OBSERVATIONS

The following observations were made on the molar teeth of a young adult[1]. Immediately after extraction the teeth were put in 10 per cent. formalin, and after hardening several months cut with a carborundum saw into longitudinal slices about 2 mm. thick. The pieces were then decalcified for about a year in a 10 per cent. formalin solution acidified with ½ per cent. hydrochloric acid. When the dentine had become thoroughly pliable the material was transferred to pyridine for two days, and then stained by the Bielschowsky block method. For examination the tissue was embedded in paraffin and cut into thick sections ($25\,\mu$).

The Bielschowsky method, as is well known, is unaccountably capricious, and many failures or only indifferent impregnations are often obtained; but the extraordinarily brilliant preparations that it sometimes yields compensate for this. The following description is based on the examination of material in which the impregnation had been very successful.

Before proceeding to describe the innervation of the pulp, brief reference may be made to the structure of the region specially concerned, namely the superficial layers of the pulp and the adjoining inner margin of the dentine. In Bielschowsky preparations of decalcified teeth most of the dentine colours only weakly, so that any stained nerve filaments that occurred in it could hardly escape detection. The inner margin of the dentine is very irregular and unfortunately is apt to stain very deeply (see figures 2, 4, 5). Immediately internal to this, in teeth that are not yet fully grown, is the odontogenic zone imperfectly or not at all calcified, but with dentinal tubes already visible.

[1] For the material I am indebted to Dr C. E. Allen of the Australian College of Dentistry, at whose request this work was undertaken.

Beneath this is a space (lymph space?) traversed by the processes of the odontoblast cells (Tomes' fibres), on their way to the dentinal tubes. This sub-dentinal zone of odontoblast processes is bounded on its inner margin by a peculiar membrane composed of collar-like attachments to the odontoblast processes, and first described by Paul (1902). The existence of these "collars" has been doubted; in the Bielschowsky preparations they appear, however, with great clearness, and seem to be developed from the odontoblasts themselves. The odontoblast cells lie immediately under this "membrane." They are smaller and closer packed in the lower part of the tooth and usually bigger and more loosely packed in the crown. From their inner aspect there arise numerous fine filaments that grow deeper forming a distinct pale layer in the pulp, the layer of Weil. The existence of this zone has been disputed (v. Ebner, Röse) on the ground that it is a shrinkage artefact. But in Bielschowsky preparations, which are admirably adapted for the purpose, its composition from fibres, derived largely from the odontoblast processes, is very clear. It is not equally prominent everywhere; sometimes it is seen to contain branching connective tissue cells (fig. 1).

The nerves, entering the tooth through the apical opening, traverse the pulp mainly in bundles as described by Huber. Many of the fibres are obviously medullated; the Bielschowsky method is not adapted for distinguishing the finer medullated fibres from the unmedullated ones. In the pulp they branch considerably. Just internal to the odontoblast layer the branching is often especially evident (fig. 1), numerous fine filaments thus arising, non-medullated and often of extreme tenuity. They are frequently varicose and are often hard to distinguish from the fine fibrous processes that grow from the odontoblast cells into the pulp, forming the pale layer of Weil. In thick sections it is possible to trace many of the fine nerve fibres past the layer of the odontoblast cells, almost to the inner margin of the dentine (sub-dentinal zone) where they usually turn and branch, running often for considerable distances parallel to the dentine as excessively fine filaments amongst the odontoblast processes. There are places in the preparations where the odontoblast processes are packed close together and soon enter the dentinal tubes; this is especially the case in the crown region, and precise observations are then very difficult to make. But in those regions where the sub-dentinal zone is wider (in my material it is at the sides of the tooth) the processes do not immediately enter the dentinal tubules; and if, as often happens, the processes are well separated from one another, the conditions for observing these very fine nerve filaments are ideal. Under very high magnifications these fine fibres, as they pass amongst the odontoblast processes appear, with their minute varicosities, like fine threads of spider web with adhering drops of moisture. The fine filaments give off collaterals which may undergo further branching. Eventually, unless they emerge from the plane of the microtome section, they terminate by definite end organs on the processes of the odontoblasts. The end organs are minute conical or leaf-like expansions of the terminal filaments; they do not end "free" but are attached to the surface of the odontoblast process. As already remarked, these endings are to be seen mainly at the sides of the teeth, where conditions for precise observation are favourable. In my preparations they only occasionally appear in the crown region; but it would be incorrect to infer from this alone that they are comparatively uncommon here, for there are immense numbers of fine nerve fibres in the crown just under the odontoblast layer, for which no certain endings can be found.

Although terminal filaments may usually be seen ending in large numbers on the odontoblast processes in the sub-dentinal zone yet examples may sometimes be seen where a definite end-organ is situated at the entrance to a dentinal tube (e.g. fig. 4). Or again, a fibre may occasionally be found which actually appears to pass into the dentine (figs. 2, 5). On account of the deep staining of the lower margin of the dentine it is not possible to follow these particular fibres to their end-organs. But it does not seem probable that these occasional fibres pass far along the dentinal tubes, because immediately beyond the deeply staining margin they are no longer seen. It would be unjustifiable to look upon this as affording confirmation of Mummery's view of an innervation of dentine; the greater part of the dentine is completely free from visible nerve fibres and the few fibres that enter the tubes doubtless pass only a very short distance along them, probably ending there on the intratubular extension of the odontoblast process.

Variations from the above described condition are sometimes found. Occasionally comparatively coarse fibres may pass, without branching, past the layer of the odontoblast cells to the inner margin of the dentine. In the zone of the odontoblast processes they may turn and travel as quite coarse fibres along the under surface of the dentine, or they may branch into typical fine varicose filaments (fig. 6), giving off end-organs to the odontoblast processes. Sometimes, though not often, the nerves may form end-organs on the odontoblast processes without developing the fine filaments that run so characteristically for long distances below the dentine. An example is shown in fig. 3. Occasionally even comparatively coarse fibres are seen thus to terminate.

Although the endings of nerve fibres are most readily to be seen in the sub-dentinal zone of odontoblast processes, yet nerves appear to terminate also on the bodies of the odontoblast cells, where others have already described them. Many of the fibres that arise from the branching of axons below the layer of Weil are excessively fine varicose filaments, quite as delicate as those that are found in the sub-dentinal zone. They pass towards the odontoblast cells. But it is very difficult to follow them to their destination, for they do not stand out in sharp contrast against the background of strongly stained closely packed odontoblast cells. Nevertheless, in places where clearer observation can be made, apparently definite endings can be found for them. These appear merely as slightly enlarged varicosities or loops (fig. 7). They are not such definite end-organs as those already described on the odontoblast processes in the sub-dentinal zone, and the possibility must be reckoned with that they are merely varicosities beyond which the staining of the fibres has suddenly failed. Thus in fig. 7 it is obviously very difficult to be certain that the globular endings of the fibres are genuine nerve end-organs. This is, of course, a difficulty that is commonly experienced in searching for the true endings of very delicate nerve filaments; for unless the endings are recognisable either by their relation to another cell, or by the presence of obvious end-organs there is no certain way by which we can discriminate between true endings and these apparent ones. Perhaps the most conclusive evidence that the nerve endings seen among the odontoblast cells are genuine endings and not the result of incomplete staining of fibres on their way to the sub-dentinal zone lies in the fact that sometimes nerves in this latter zone may form branches that actually grow back again into the pulp and evidently end there on the bodies of the odontoblast cells (fig. 2).

I have not been able to find instances of nerve terminals forming basket-works around the cells; nor have I seen any indication of nerve cells in the pulp, as described by Mummery.

The above observations then offer no support for the view that the dentine is itself traversed by nerve fibres. The evidence rests not merely on a failure to demonstrate nerves in the dentine, but on the fact that definite end-organs, associated with the odontoblasts can be demonstrated in the sub-dentinal zone. It would seem to follow therefore that the odontoblast processes in the dentine must be the receptor organs for these nerve endings; and if they can serve as receptors, then one can at present see no reason for inferring a special innervation of the dentine to account for clinical facts, when the microscopical evidence does not support it.

SUMMARY

1. The endings of nerves have been examined in Bielschowsky preparations of decalcified human molar teeth.

2. From the deeper region of the pulp nerves can be followed, right through the zone of odontoblast cells, into the sub-dentinal zone of odontoblast processes. Here they turn and can be followed as excessively fine, varicose branching filaments that run, often for considerable distances immediately under the dentine among the odontoblast processes. On these processes they terminate by definite end-organs which are attached to their surface.

3. Occasionally the nerves may end without forming these long varicose filaments.

4. Sometimes even quite coarse fibres may be seen running for long distances in the sub-dentinal zone.

5. Very delicate nerve filaments appear also to terminate by minute swellings (loops) on the bodies of the odontoblasts.

6. No evidence has been found for an extensive innervation of dentine, as described by Mummery and others. No nerve cells have been seen in the pulp.

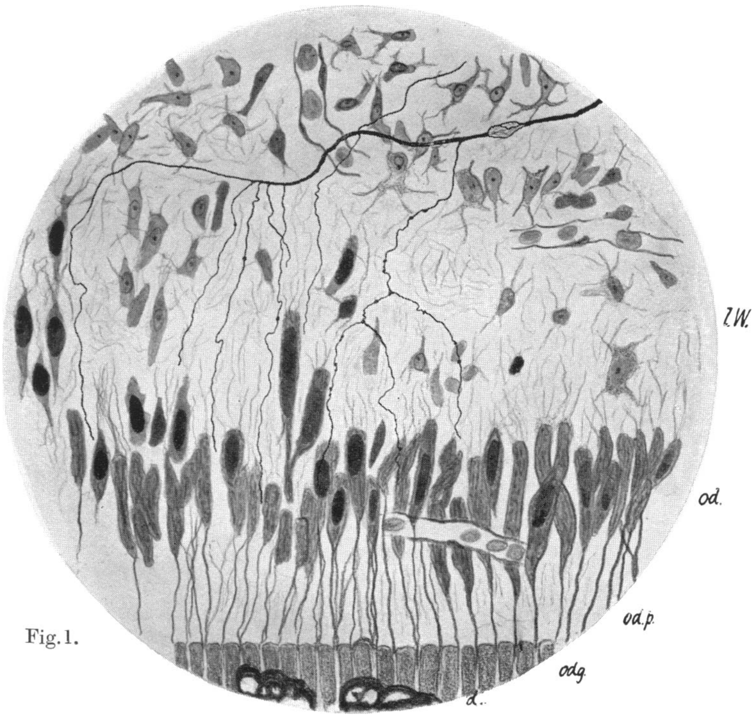

Fig. 1.

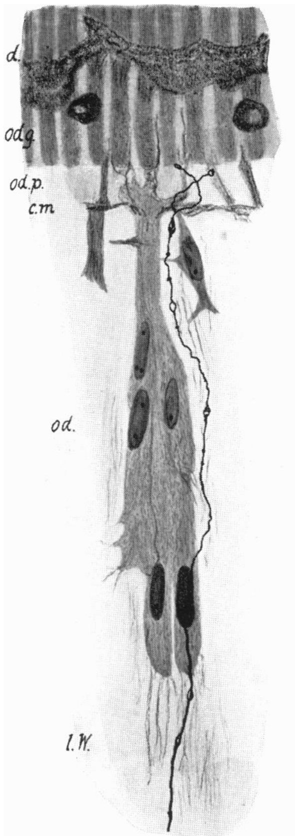

Fig. 3.

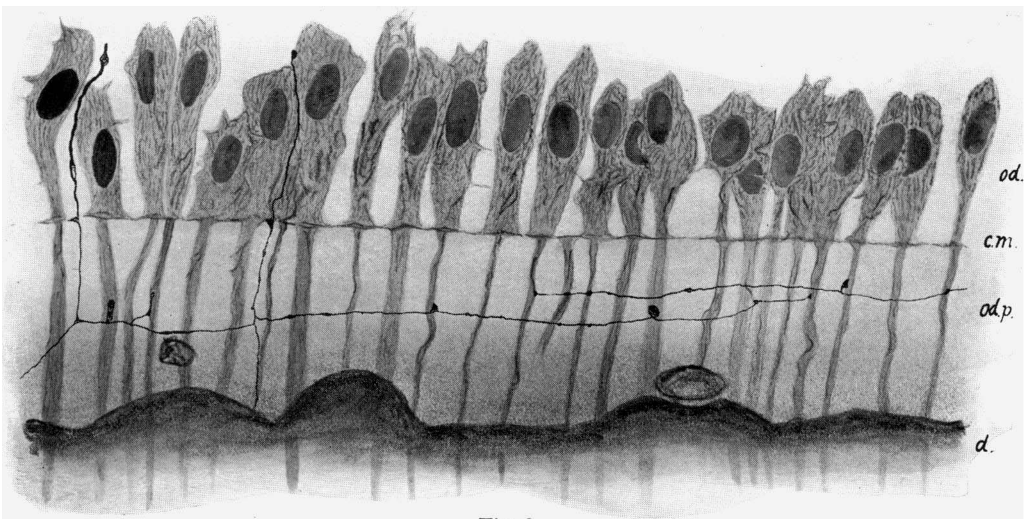

Fig. 2.

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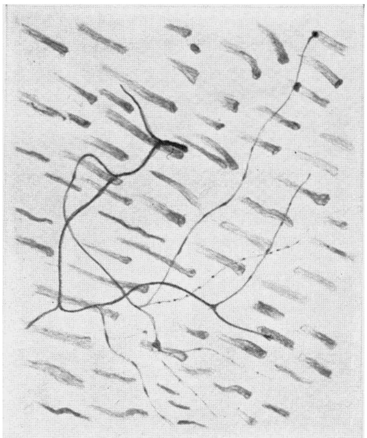

Fig. 6.

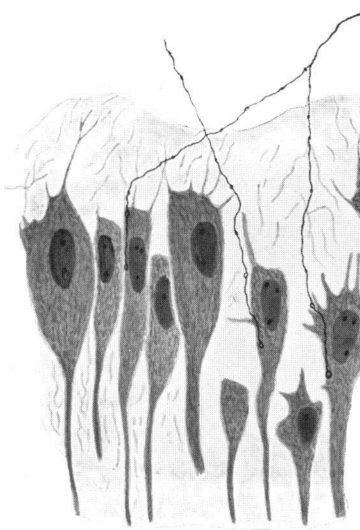

Fig. 7.

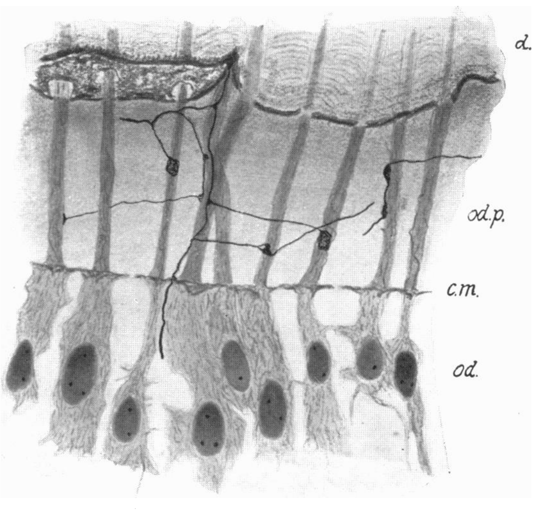

Fig. 4.

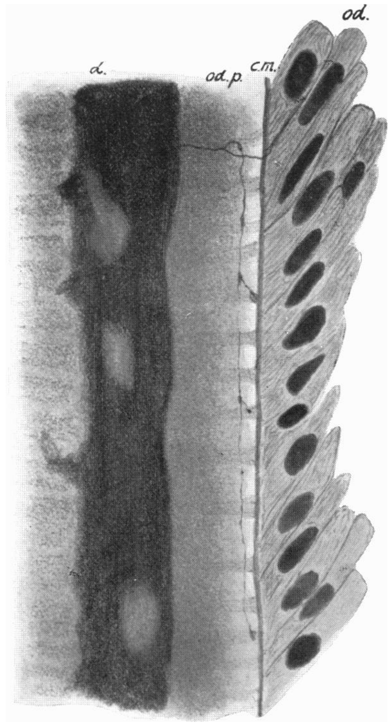

Fig. 5.

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EXPLANATION OF PLATES

The various zones at the junction of pulp and dentine are indicated thus: *d.* mature dentine; *odg.* odontogenic zone; *od.p.* sub-dentinal zone of odontoblast processes; *c.m.* "membrane" composed of the collars of the odontoblast cells; *od.* odontoblasts; *l.W.* layer of Weil.

Figs. 1–2 reduced by ¼; figs. 4–7 reduced by ⅕.

PLATE I

Fig. 1. To show branching nerve fibres in the surface region of the pulp. The fine varicose fibres pass among the odontoblast cells; when examined under higher magnification it appears improbable that the "endings" of the fibres are the true terminations. Zeiss homog. immers. $\frac{1}{7}$ in.; oc. × 15.

Fig. 2. A medium sized nerve fibre penetrates the odontoblast zone, branches in the sub-dentinal zone, and turning, runs as a delicate varicose filament among the odontoblast processes, on several of which it terminates by definite end-organs. A single short branch is seen to grow back among the odontoblasts, apparently to terminate there, whilst another branch passes to a dentinal tubule, but becomes obscured by the deeply staining lower margin of the dentine. Zeiss apochromat. 2 mm., oc. × 15.

Fig. 3. A comparatively coarse nerve fibre ending in the sub-dentinal zone without the formation of the usual type of long terminal filaments. Zeiss apochromat. 2 mm., oc. × 15.

PLATE II

Fig. 4. Fine nerve fibres branching among the odontoblast processes, and ending there by definite end-organs. Note the presence of an end-organ at the entrance to a dentinal tubule. Zeiss apochromat. 2 mm., oc. × 15.

Fig. 5. Fine nerve filaments with end-organs on the odontoblast processes in the sub-dentinal zone, towards the lower end of the tooth. A branch actually appears to enter a dentinal tubule but cannot be followed on account of the deep staining of the dentinal margin. Zeiss apochromat. 2 mm., oc. × 15.

Fig. 6. A comparatively coarse nerve fibre branching into fine nerve filaments among the odontoblast processes. Four end-organs are visible. Zeiss apochromat. 2 mm., oc. × 15.

Fig. 7. Fine nerve filaments apparently terminating on the bodies of the odontoblast cells. Zeiss apochromat. 2 mm., oc. × 15.